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UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Agricultural Engineering

SIMPLIFIED PITOT TUBE CALCULATIONS OF AIR FLOW IN DUCTS AND PIPES

By Chas. A. Bennett, Senior Mechanical Engineer

Many engineers have difficulty in making air-volume calculations in the ducts or piping systems of fans and blowers. With ordinary care, using a calibrated pitot tube and sensitive gages, it is not difficult to secure accurate readings in ducts and air pipes. If the engineer is not familiar with methods of taking such readings, he may refer to any college text book on ventilation, to the "Standard Test Code" promulgated by the American Society of Heating and Ventilating Engineers, or to certain pamphlets distributed by manufacturers of fans.

Flow of air in cubic feet per minute is calculated from the velocity-pressure or velocity-head readings of the pitot tube. The basic formula for the flow of a fluid of uniform density is

$$V = \sqrt{2gh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which
- V = velocity in feet per second,
- g = acceleration due to gravity (32.16 ft. per second per second), and
- h = head in feet of the fluid for which V is being computed.

For a gas (air is a gas) h in formula 1 may be considered the same as the height of a column of fluid of the same density as the gas being measured that will exert a pressure equal to the pressure causing the flow. By the introduction of a proper coefficient, V and h can be expressed in any desired units.

To adapt this formula to the measurement of air flow, let

- V' = velocity of air in feet per minute;
- h' = head in inches of water;
- W = weight per cubic foot of atmosphere at the test conditions of temperature, humidity, and barometric pressure;
- $k = \sqrt{1/W} = \sqrt{\text{cubic feet per pound of atmosphere}}$.

Then formula 1 may be written

$$V' = 1096.2\ k\sqrt{h'} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

For atmospheric temperature of 70 degrees F., relative humidity of 70 percent, and barometric pressure of 30 inches of mercury, this becomes

$$V' = 4012\sqrt{h'} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

It should be kept in mind that W is the weight of one cubic foot of atmosphere. Atmosphere is composed of dry air and water vapor. The higher the relative humidity, the greater will be the velocity under conditions of constant velocity head. Values for W may be obtained from the tables of the United States Weather Bureau, or may be calculated. Figure 1 gives the cubic feet of atmosphere per pound, the reciprocal of W, under many conditions of temperature, at 30 inches barometric pressure.

For any atmospheric condition, k may be calculated as the square root of the volume in cubic feet determined from figure 1, for use in these formulas.

From many tests, the United States Navy has found that the mean velocity for an entire duct (round or its equivalent) is 91 percent of the velocity at the center of the pipe; hence

$$V_a = 997.5\ k\sqrt{h_v} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

where V_a = mean velocity of air in feet per minute

h_v = velocity head at center of pipe.

In cotton-gin work most of the readings will be taken with a pitot tube at the center of the pipe. Table 1 gives values for 997.5 k.

Table 1.- Values of 997.5 k in formula $V_a = 997.5\ k\sqrt{h_v}$
(Barometric pressure, 30.0 inches)

Atmosphere conditions		997.5 k
Temperature (F.)	Relative humidity	
Degrees	Percent	
	0	3609
60	50	3615
	100	3621
	0	3645
70	50	3653
	100	3661
	0	3679
80	50	3691
	100	3703

Graphs from which can be read the mean velocity in feet per minute of the atmosphere within the pipe will enable an engineer to make the entire calculation on the spot, concurrent with the pitot tube readings. Figure 2 was prepared for cotton ginning conditions in the Mississippi Delta region, and is based upon 70 degrees (F.) temperature, 70 percent

relative humidity, and 30 inches barometric pressure. It has been found to be sufficiently accurate for the entire cotton belt, and is correct within one percent for all humidities from 0 to 100 percent at a temperature of 70 degrees.

By use of figure 2 difficulties with pitot tube readings are eliminated and the engineer can make complete findings on the test grounds. If his results show that the rates of flow per minute are not what he believes they should be, he can find this out at once and look for causes of the trouble. With such charts it is easy to instruct assistants in making accurate observations.

In making field calculations by this method, the first step is to obtain the velocity head, h_v, by use of the pitot tube. To insure accuracy, the pitot tube must be inserted in a straight section of pipe where the instrument will be as free as possible from effects of cavitation and eddies in the air flow. Standardized fan tests require that there must be $7\frac{1}{2}$ diameters of pipe as a straight length to the point of insertion of the pitot tube, but, in cotton-ginning installations, it is frequently not possible to obtain more than 4 diameters in a straight section at points where instruments may be set up. The pitot tube may be placed on either the suction or discharge side of the fan, but the discharge side is to be preferred where convenient.

The second step is that of making the necessary interpolation from figure 2 to determine the mean velocity for the given velocity head, h_v.

The third step is computation of the cubic feet per minute flowing through the pipe. This may be obtained by direct calculation, in which the mean velocity V_a is multiplied by the area of the pipe in square feet, which may be obtained from table 2; or the rate of flow may be approximated by using the chart in figure 3.

Table 2.- Cross-sectional area of cotton-gin piping

Diameter of pipe	Cross-sectional area of pipe
Inches	Square feet
8	0.3491
9	0.4418
10	0.5454
11	0.6600
$11\frac{1}{2}$	0.7215
12	0.7854
$12\frac{1}{2}$	0.8522
13	0.9218
$13\frac{1}{2}$	0.9940
14	1.069
$14\frac{1}{2}$	1.147
15	1.227
16	1.396

Cotton ginning practices usually require mean velocities of 2,000 to 4,500 feet per minute for handling seed cotton, and from 4,000 to 6,000 for handling cottonseed. Air-blast gins usually require from 155 to 175 cubic feet of air per 10 saws, and cotton unloading fans that do not blow seed have successfully operated with flows ranging from 600 to 900 cubic feet per minute per gin stand.

At times in cotton ginning, especially in cotton drying work, it is desirable to ascertain what change occurs in relative humidity when atmosphere at one particular condition is heated from one temperature to another. This may be determined from figure 4. (Reproduced from U.S.D.A. Weather Bureau Bulletin No. 235).

Table 3 will be found useful in determining the relative humidity from the readings of wet and dry bulb thermometers. This table has been compiled from Weather Bureau Bulletin 235 and Department Bulletin 1136.

To use the table: Suppose the dry bulb reads 140° and the wet bulb 130°, a difference of 10°. Find 140 in the left-hand column; follow across to the column headed 10; the relative humidity is 75 percent.

Table 3.- Relative humidity in percent
(Pressure = 30 inches)

Air Temp. Dry Bulb:	Difference Between Wet and Dry Bulb Thermometers in Degrees Fahrenheit																																							
Reading Degrees Fahrenheit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5	0																							
51	94	87	81	75	68	62	56	50	45	39	34	28	23	17	12	7	2																							
52	94	87	81	75	69	63	57	51	46	40	35	29	24	19	14	9	4																							
53	94	87	81	75	69	63	58	52	47	41	36	31	26	20	16	10	6	1																						
54	94	88	82	76	70	64	59	53	48	42	37	32	27	22	17	12	8	3																						
55	94	88	82	76	70	65	59	54	49	43	38	33	28	23	19	14	9	5	0																					
56	94	88	82	76	71	65	60	55	50	44	39	34	30	25	20	16	11	7	2																					
57	94	88	82	77	71	66	61	55	50	45	40	35	31	26	22	17	13	8	4																					
58	94	88	83	77	72	66	61	56	51	46	41	37	32	27	23	18	14	10	6	1																				
59	94	89	83	78	72	67	62	57	52	47	42	38	33	29	24	20	16	11	7	3																				
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1																			
61	94	89	84	78	73	68	63	58	54	49	44	40	35	31	27	22	18	14	10	7	3																			
62	94	89	84	79	74	69	64	59	54	50	45	41	36	32	28	24	20	16	12	8	4	1																		
63	95	89	84	79	74	69	64	60	55	50	46	42	37	33	29	25	21	17	13	10	6	2																		
64	95	90	84	79	74	70	65	60	56	51	47	43	38	34	30	26	22	18	15	11	7	4	0																	
65	95	90	85	80	75	70	66	61	56	52	48	44	39	35	31	27	24	20	16	12	9	5	2																	
66	95	90	85	80	75	71	66	61	57	53	48	44	40	36	32	29	25	21	17	14	10	7	3	0																
67	95	90	85	80	75	71	66	62	58	53	49	45	41	37	33	30	26	22	19	15	12	8	5	2																
68	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	31	27	23	20	16	13	10	6	3																
69	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	32	28	24	21	18	14	11	8	5	1															
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3															
71	95	90	86	81	77	72	68	64	60	56	52	48	45	41	37	33	30	27	23	20	17	13	10	7	4	1														
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	34	31	28	24	21	18	15	12	9	6	3														
73	95	91	86	82	78	73	69	65	61	57	53	50	46	42	39	35	32	29	25	22	19	16	13	10	7	4	1													
74	95	91	86	82	78	74	69	65	61	58	54	50	47	43	39	36	33	29	26	23	20	17	14	11	8	5	3													
75	96	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34	30	27	24	21	18	15	12	9	7	4	1												
76	96	91	87	82	78	74	70	66	62	59	55	51	48	44	41	38	34	31	28	25	22	19	16	13	11	8	5	3												
77	96	91	87	83	79	74	71	67	63	59	56	52	48	45	42	39	35	32	29	26	23	20	17	14	12	9	6	4												
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	36	33	30	27	24	21	18	16	13	10	8	5												
79	96	91	87	83	79	75	71	68	64	60	57	53	50	46	43	40	37	34	31	28	25	22	19	17	14	11	9	6												
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	0									
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45	42	39	36	33	30	28	25	22	20	17	14	12	10	7	5	2	0								
84	96	92	88	84	80	76	73	69	66	62	59	56	52	49	46	43	40	37	35	32	29	26	24	21	19	16	14	12	9	7	5	3	0							
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47	44	42	39	36	33	31	28	26	23	21	18	16	14	11	9	7	5	3	1						
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48	46	43	40	37	35	32	30	27	25	22	20	18	15	13	11	9	7	5	3	1					
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	11	9	7	5	3	1				
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50	48	45	42	40	37	35	32	30	28	25	23	21	19	17	15	13	11	9	7	5	3	1			
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49	46	43	41	38	36	33	31	29	27	24	22	20	18	16	14	12	10	9	7	5	3	1		
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50	47	44	42	39	37	35	32	30	28	26	24	22	20	18	16	14	12	10	8	7	5	3	2	0
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53	50	48	45	43	40	38	36	34	32	29	27	25	23	21	19	17	15	14	12	10	8	7	5	3	2
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	19	17	15	13	12	10	8	7	5	4
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	13	11	10	8	7
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25	24	22	20	19	17	16	14	12	11	10
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58	55	53	51	49	47	44	42	40	38	36	35	33	31	29	27	26	24	23	21	19	18	16	15	14	12
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59	57	54	52	50	48	46	44	42	40	38	36	34	33	31	29	28	26	25	23	22	20	19	17	16	14
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	29	28	26	25	23	22	21	19	18	17
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61	59	57	54	52	50	48	47	45	43	41	39	38	36	34	33	31	30	28	27	25	24	22	21	20	18
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60	58	56	54	52	50	48	46	44	42	41	39	37	36	34	33	31	30	28	27	25	24	23	22	20
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	58	56	55	53	51	49	47	45	44	42	40	39	37	36	34	33	31	30	28	27	26	24	23	22
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63	61	59	57	55	54	52	50	48	46	45	43	41	40	38	37	35	34	33	31	30	28	27	26	25	23
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	37	35	34	32	31	30	29	27	26	25
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47	45	44	42	41	39	38	36	35	34	32	31	30	29	27	26
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	60	58	56	54	53	51	49	48	46	45	43	42	40	39	38	36	35	34	32	31	30	28	28
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35

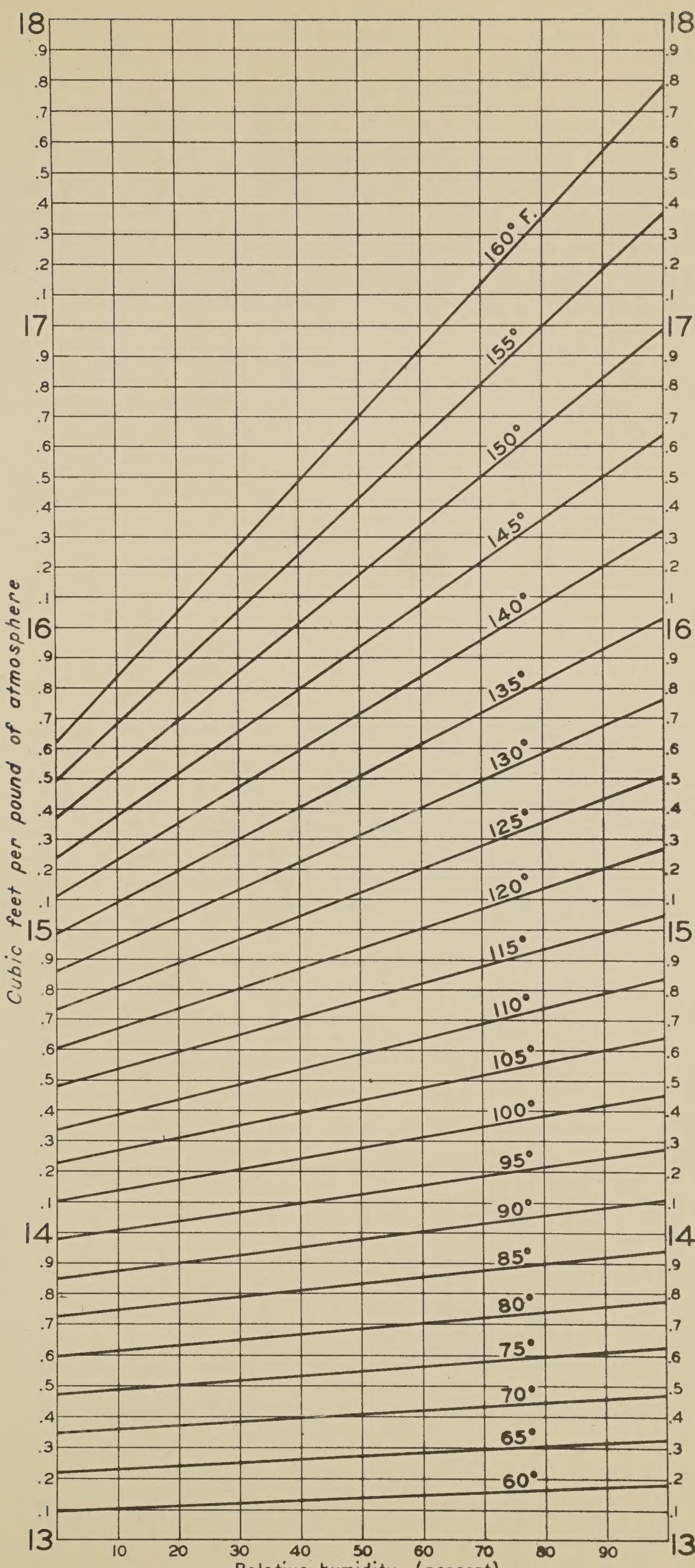

FIG. I–DENSITY OF ATMOSPHERE

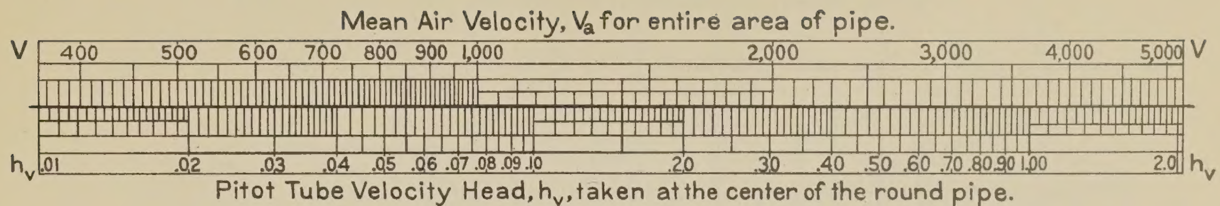

Fig. 2 - Scale of mean air velocities in round pipe in feet per minute

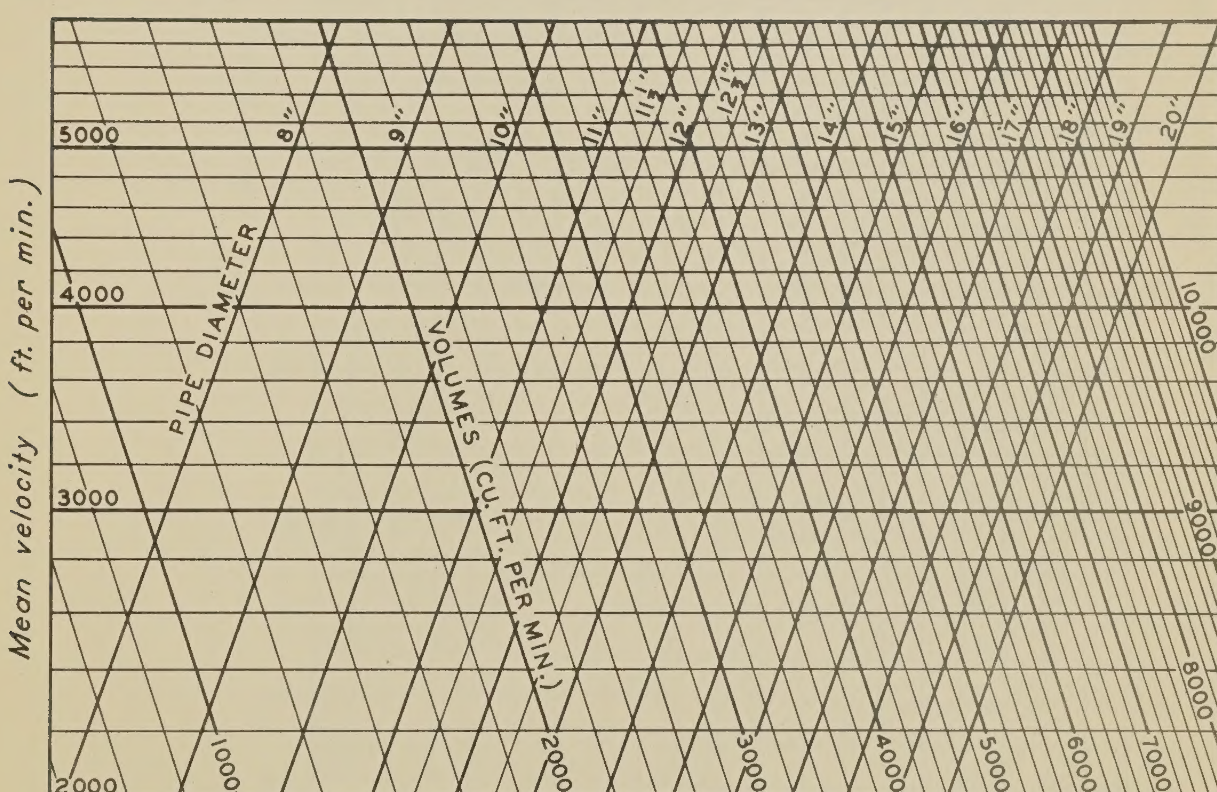

Fig. 3 - Approximate flow of air in cotton-gin piping

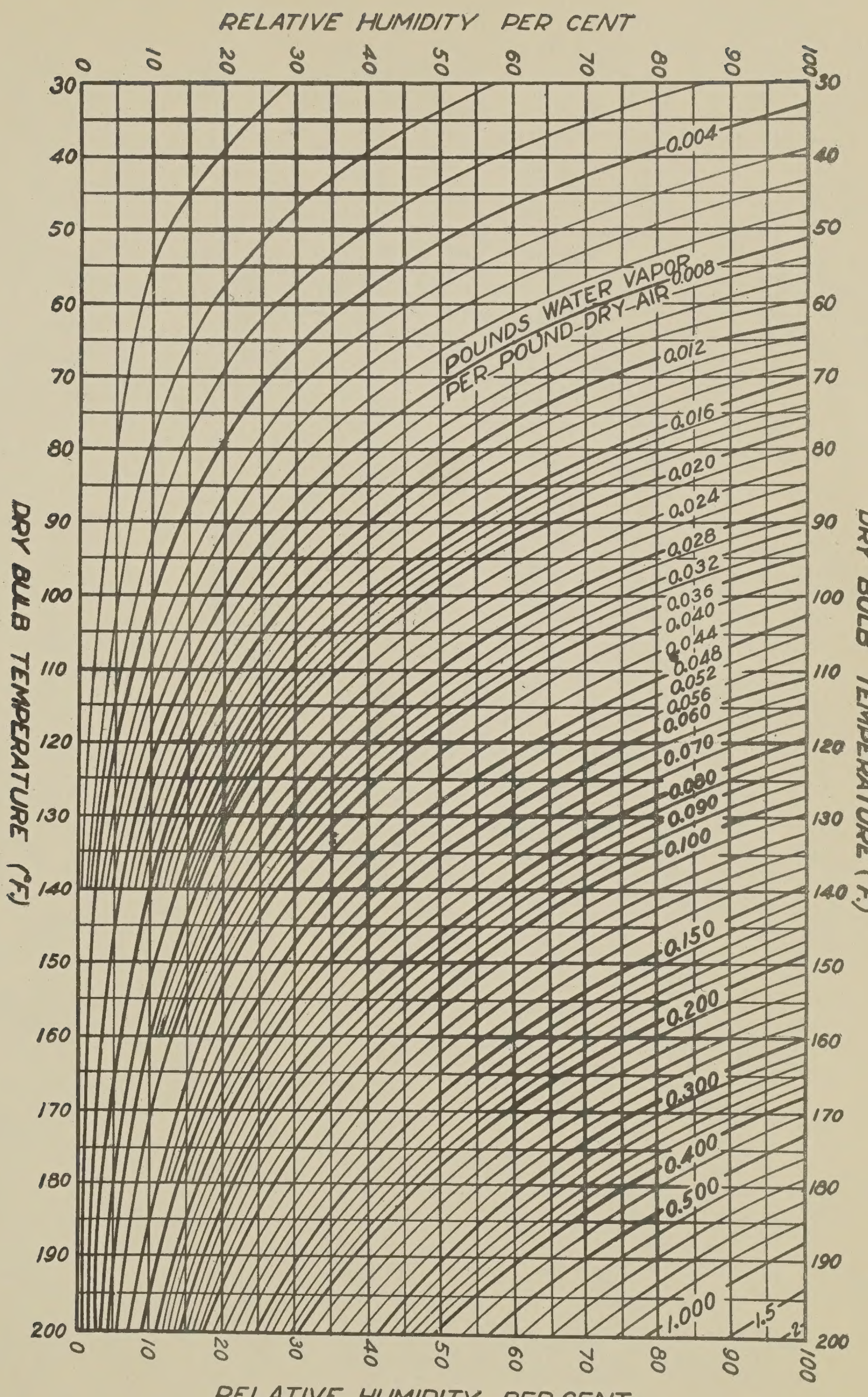

FIG. 4.—Pounds of water vapor per pound of dry air